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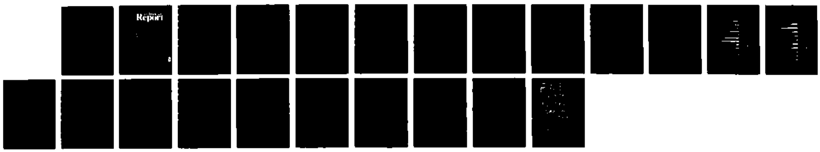

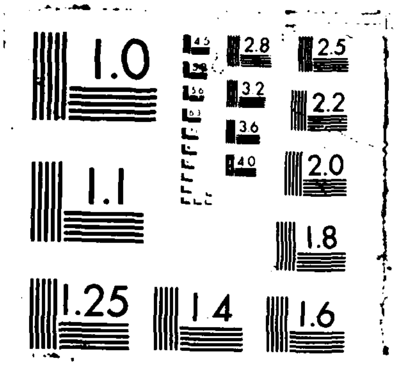
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technical Report

United States Army
Belvoir Research, Development & Engineering Center
Fort Belvoir, Virginia 22060-5606

Report 2459

Investigation of Waveform Distortion in Mobile Electric Power Systems

Authored By: Systems Assessment Team

Report Date: December 1987

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[illegible] DOD power generator systems were tested by Belvoir RD&E Center's [illegible] measurements [illegible] to determine power distortion present and to demonstrate the electrical conditions that exist with these systems under normal field conditions. [illegible] Inspector General's "Report on the Survey of [illegible] Mobile Electrical Generators and Related Equipment," dated Feb 86.

[illegible] report [illegible] distortion [illegible] results, the present generator [illegible] requirements are adequate to ensure satisfactory system [illegible].

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PREFACE

In February 1986, the Office of the Inspector General released the *Report on the Survey of Acquisition of Mobile Electric Generators and Related Equipment*. That report resulted from allegations made by a commercial firm and other complainants regarding Department of Defense generators. The report's objectives were to:

- examine allegations regarding the cost and benefits associated with using "true-Root-Mean-Square" (true-RMS) meters and instruments instead of the absolute average responding devices currently used on Army generators;
- review the quality of power produced by mobile electric generators;
- determine if existing test specifications and practices ensure the desired quality of power is achieved; and
- evaluate specific allegations concerning procurement practices for watt converters, electrical test sets, and voltage regulators.

In the report's conclusions and recommendations, the Office of the Inspector General felt that the Army Materiel Command's Systems Assessment Office should make field tests of power distortion presence on weapon systems power lines. These tests were to demonstrate the electrical conditions that exist with systems under normal field conditions.

The Systems Assessment Team at the Belvoir Research, Development and Engineering Center was tasked by the Project Manager, Mobile Electric Power, to conduct a series of field tests. The purpose of these tests, which began in October 1986, was to determine representative levels of waveform distortion experienced under typical field operation conditions. Ten fielded systems were tested. The work was authorized under Department of the Army Project 1S464714D194, Engine Driven Generators. The Product Assurance and Engineering Directorate's Test and Test Policy Divison, in cooperation with the Systems Assessment Team, conducted the tests. This technical report describes the results of these tests.

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TABLE OF CONTENTS

SECTION I. BASIC PROCEDURE

1. Select operating conditions and environments which are representative of actual field usage.

2. Connect waveform measuring equipment between generator set output and system.

3. Measure waveform, including total harmonic distortion and maximum single harmonic of phase voltages and currents imposed on the generator supplying power to the system.

(Refer to Appendix for detailed test procedure, instrumentation list, analysis procedures, and representative voltage and current waveforms.)

SECTION II. SYSTEMS AND RESULTS

The following data summarizes the results of the testing conducted on ten systems. There was no observed degradation of performance of the systems tested, even though the generator set specified voltage deviation factor was exceeded in five tests. Figures 1 and 2 present test data summaries.

1. One Topographic Support System (TSS) using two separate 60kW, 50/60 Hz generator sets (MEP-006A) as the power source.

The maximum power observed on the TSS during operation was 29.88 kW with a 0.98 power factor (pf). The maximum voltage deviation factor was 3.78%, with a total harmonic distortion (THD) of 1.66% on phase A during operation at 21.5 kW.

2. One AN/TPQ-36 FIREFINDER Radar System using a 10 kW, 400 Hz generator set (MEP-112A) as the power source.

The maximum power observed on the AN/TPQ-36 system during full operation with antenna radiating was 6.44 kW with a 0.98 pf. The maximum voltage deviation factor was 2.76%, with a THD of 1.16% on phase C during full operation. Operating under no load, the voltage deviation factor of 1.82% with THD of 0.60%.

3. Two PATRIOT EPP II's using 150 kW, 400 Hz gas turbine engine driven generator sets as the power source.

A review of prior data taken on the PATRIOT missile system showed a maximum THD of 8.03% on phase A in the high power radiate mode.

4. One AN/TAM-4 Bottle Cleaning/Charging Station using a 30 kW, 60 Hz generator set (MEP-005A) as the power source.

During the test of the AN/TAM-4A station, a maximum of 14.1 kW power demand (47% of rated power) was recorded. At this peak load, the voltage and current waveforms were the most distorted; the maximum voltage deviation factor was 4.93%, with a THD of 1.4%; and the maximum current deviation factor was 11%, with a THD of 4.7%.

5. One AN/TSC-118 High Frequency Central Communications Radio using a 60 kW, 400 Hz gas turbine engine driven generator set (MEP-404A) as the power source.

During the test of AN/TSC-118, a maximum of 41.4 kW power demand (69% of rated power) was recorded. The voltage and current waveforms at this peak load were the most distorted; the voltage deviation factor was 4.94%, with a maximum THD of 3.17%; and the current deviation factor was 7.22%, with a maximum THD of 8.58%. Operating under no load, the voltage deviation factor was 2.04% with a maximum THD of 1.68%.

6. Two Digital Tropospheric Scatter Radio Terminal Sets:

One AN/TRC-170 V(2) using a 30 kW, 60 Hz generator set (MEP-005A) as a power source.

During the test of AN/TRC-170 V(2), a maximum of 19.26 kW power demand (64% of rated power) was recorded. The voltage waveforms at this peak load and the current waveforms when the systems was operating at 5.14 kW (17% of rated power) were the most distorted. The voltage deviation factor was 22%, with a maximum THD of 8.5%; and the current deviation factor was 36.6%, with a maximum THD of 25%. Operating under no load, the voltage deviation factor was 1.63% with a maximum THD of 0.95%.

One AN/TRC-170 V(3) using a 10 kW, 60 Hz generator set (MEP-003A) as a power source.

During the test of the AN/TRC-170 V(3), a maximum of 10.8 kW power demand (108% of rated power) was recorded. The voltage waveforms at this peak load and the current waveforms when the system was operating at 3.63 kW (36% of rated power) were the most distorted. The voltage deviation factor was 17.3%, with a maximum THD of 8.6%; and the current deviation factor was 33%, with a THD of 30%. Operating under no load, the voltage deviation factor was 2.33% with a maximum THD of 1.55%.

7. Pershing II (PII) Missile System.

One Platoon Control Central; using its allocated trailer mounted 30 kW, 60 Hz generator set (MEP-005A) as a power source.

During the test, a maximum of 7.3 kW power demand (24% of rated power) was recorded. At this peak load, the voltage and current waveforms of phase C were the most distorted. The voltage deviation factor was 2.1%, with a THD of 0.90%; and the current deviation factor was 10.4%, with a THD of 5.6%. Operating under no load, the voltage deviation factor was 1.31% with a maximum THD of 0.78%.

One Guided Missile Erector Launcher using its own 30 kW, 60 Hz generator set (MEP-005A) as a power source.

During the test, a maximum of 7.88 kW power demand (26% of rated power) was recorded. The voltage and the current waveforms of phase A, when the sytsem was operating at 3.6 kW (12% of rated power), were most distorted. The voltage deviation factor was 11.5%, with a maximum THD of 2.6%; and the current deviation factor was 20.3%, with a THD of 12.5%. Operating under no load, the voltage deviation factor was 1.39% with a maximum THD of 0.79%.

8. One Forward Sensor Interface and Control Module of the All Source Analysis System using a 10 kW, 60 Hz generator set (MEP-003A) as the power source.

During the test of the forward Sensor Interface and Control Module (FSIC) of the All Source Analysis System (ASAS), a maximum of 4.8 kW (49% of rated power) was recorded. The voltage waveforms were the most distorted when the generator was operating at a recorded demand of 3.97 kW (39.7% of rated power). The maximum THD at this level was 2.47%, and the deviation factor was 4.83%. The current waveforms were the most distorted when the generator was operating at a demand of 4.68 kW (46.8% of rated power). The current deviation factor was 34.6%, with a maximum THD of 22.7%. Operating under no load the volate deviation factor was 4.32% with a maximum THD of 2.0%.

9. Hawk Missile System:

One Battery Command Post (BCP), one Continuous Wave Acquisition Radar (CWAR), and one Pulse Acquisition Radar (PAR) using a 60 kW, 400 Hz generator set (MEP-115A) as the power source.

During the test, a maximum of 19.9 kW power demand (33.2% rated power) was recorded. At this peak load, the voltage waveforms were most distorted. The voltage deviation factor was 6.12% with a THD of 5.10%. The current waveforms of the BCP under full load test (3.53 kW or 5.9% of rated power) were the most distorted. The current deviation factor was 91.7% with a THD of 55.0%. Operating under no load, the voltage deviation factor was 1.73% with a maximum THD of 0.72%.

One High Power Illuminator (HPI) and three launchers with nine dummy missiles, using a 60 kW, 400 Hz generator set (MEP-115A) as the power source.

During the test, a maximum of 25.6 kW power demand (42.6% of rated power) was recorded. With the HPI at full load test (22.1 kW or 33.9% of rated power), the voltage deviation factor was 8.62% with a THD of 6.17%. The current deviation factor was 40.7% with a THD of 30.9%. Operating under no load, the voltage deviation factor was 1.73% with a maximum THD of 0.72%.

10. Turbine Engine Power Plant (TEEP); the unit was a Utility Power Plant modified to supply 60 kW, 60 Hz electric power to a field hospital set-up.

During the test, a maximum of 8.93 kW power demand (14.8% of rated power) was recorded. At this peak load, the voltage and current waveforms were the most distorted. The voltage deviation factor was 1.27% with a THD of 0.69%, and the current deviation factor was 3.34% with a THD of 1.87%.

SECTION III. DISCUSSION

In all the tests performed, two waveform parameters were measured: individual harmonics, and total harmonic distortion. The voltage and current deviation factors were calculated from the recorded data. For the voltage waveform, the related Military Specifications (see Table 1) on generator sets specifies a maximum voltage deviation factor and a maximum single harmonic at no load, rated load at unity power factor, and rated load at 0.8 power factor lagging when connected to a linear load. There presently are no specifications for current waveform or for total harmonic distortion. Even though there are no specific limits for current deviation, this "harmonic current injection" was measured to show its affect on voltage waveform.

On five occasions, the voltage deviation factor was greater than the maximum specified for the generator set when powering a linear load. Two of these instances occurred with the Digital Tropo Radio System. Both times, the system was in the radiate mode: once with on high-power amplifier, and once with two high-power amplifiers operating. The third occasion was with the Pershing II Missile System Erector Launcher. The system was in the count-down mode, with the inertial measurement system and the target loading system operating. The fourth and fifth occasions occurred with the Hawk missile system; with the BCP under full load test, and with the HPI operating with three missile launchers. Although the voltage deviation factor was significant, at no time was performance degraded for any of the systems measured.

Table 1. Military Specifications on Generator Sets

MIL-G-52884	**15 to 200 kW**
Voltage Deviation Factor	5%
Single Frequency Harmonic	2%
MIL-G-52889	**5 kW and 10 kW** (Single phase/Three phase)
Voltage Deviation Factor	6% / 5%
Single Frequency Harmonic	3% / 2%

SECTION IV. CONCLUSIONS

1. No system performance degradation was observed during the testing even though the voltage deviation factor exceeded the generator set specification in several instances.

2. System designers apparently accommodate for waveform distortion in excess of that specified for the generator set.

3. Based on the test results, the present generator set specifications for waveform requirements are adequate to ensure satisfactory system operation.

SECTION V. FUTURE PLANS

Waveform distortion measurements normally will be recorded during all on-site surveys of field power systems. In addition, the Product Assurance and Engineering Directorate, Belvoir RD&E Center, will update and maintain the waveform database indefinitely. The database consists of file copies of all the individual test reports to date and all the magnetic media (raw data).

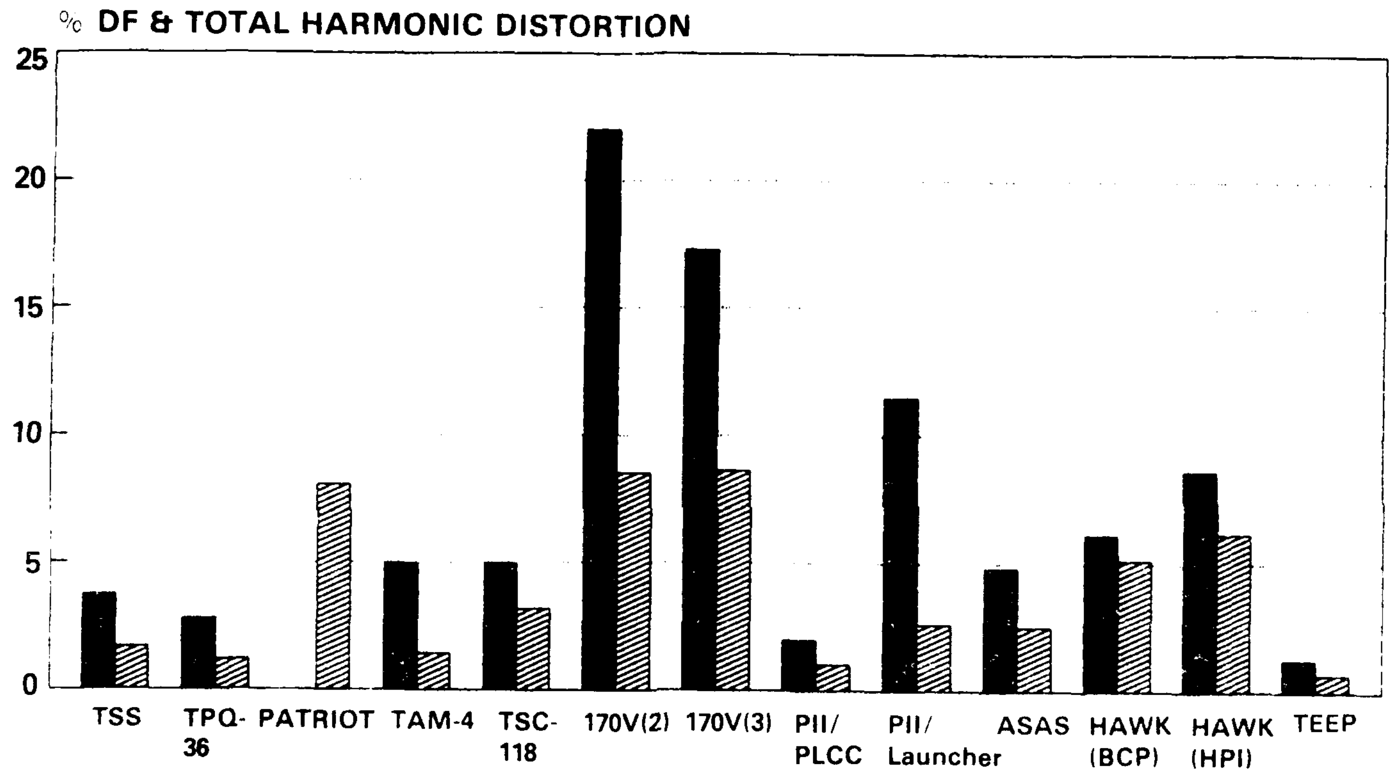
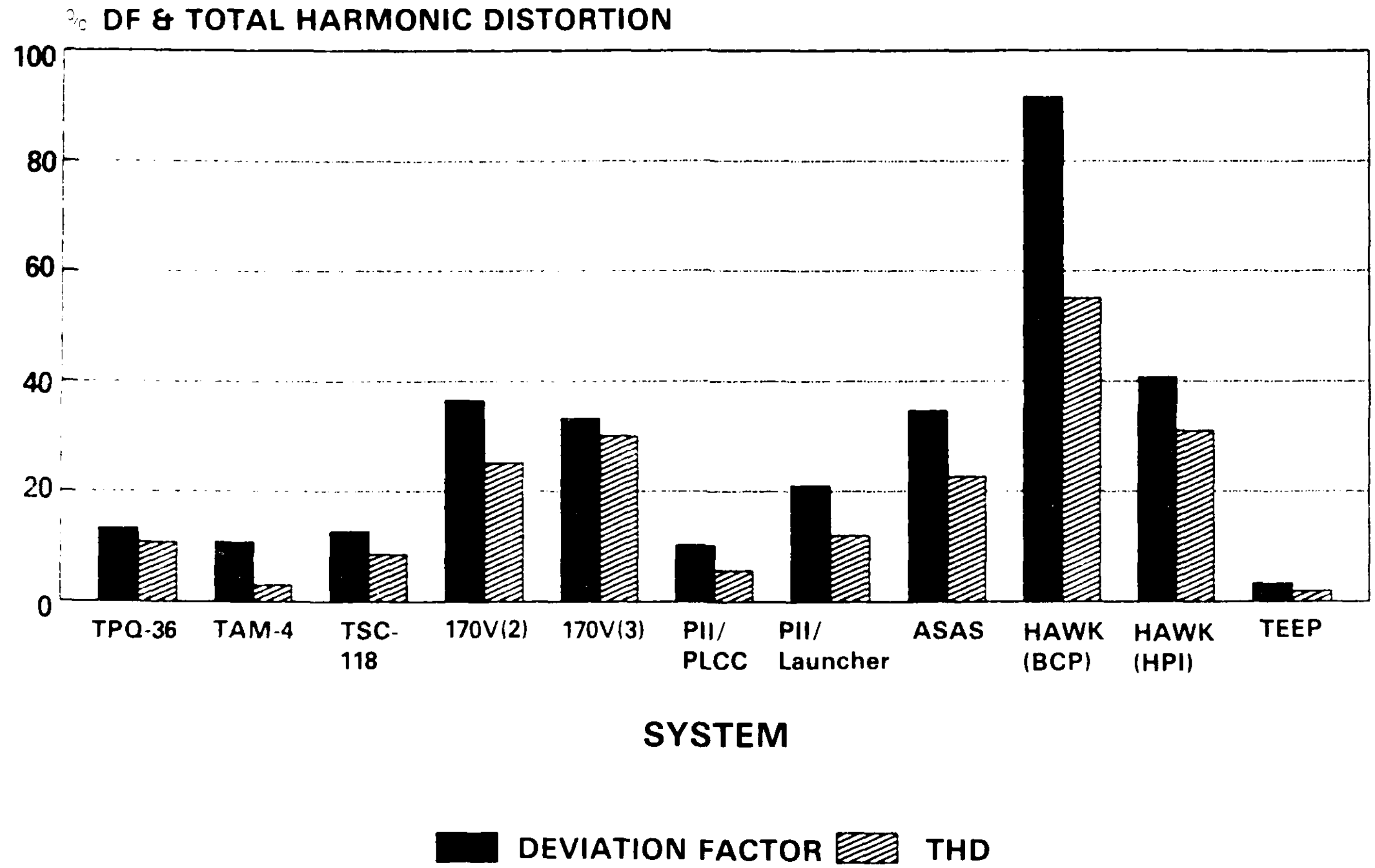


Figure 1. Test Data Summary (Voltage)



DATA UNAVAILABLE FOR TSS & PATRIOT

Figure 2. Test Data Summary (Current)

APPENDIX: DETAILED TEST PROCEDURE

INSTRUMENTATION

The Belvoir Power Systems Assessment Van was used to transport personnel and equipment to the individual test sites and served as a mobile instrumentation laboratory.

The Dranetz 808 Power Demand Analyzer was used to record power parameters. It was attached for three-phase monitoring via clamp-on transformers on each phase and clip lead voltage sensing to each phase, neutral, and earth ground. The unit was then programmed to measure volts, amps, kVA, kW, and power factor at 1- minute intervals. In addition, the analyzer was manually triggered after each mode of operation change.

The Dranetz 3105 Precision Power and Harmonic Analyzer was used to record voltage and current waveform data. The analyzer is a unique microprocessor-based dual channel precision instrument designed to perform complex power measurements and waveform analysis. Employing Fast Fourier Transform analysis techniques, the analyzer measures fundamental, total, and each harmonic to the 50th of all parameters within its frequency range (1 Hz to 500 kHz), with accuracies of up to ± 0.04% (magnitude) and ± 0.03 degree.

- The two non-isolated channels were used. Since both inputs must be voltage, current transformers were used to monitor current. One channel was programmed for amps, and a scale of volt-ampere ratio was entered to provide the volt-ampere conversion. The other channel was programmed for volts.

- The first channel (voltage) was coupled to the output of a three-phase voltage switch, which was attached to the generator set via a four-conductor cable so that each line-to-neutral voltage could be monitored separately.

- The second channel (current) was coupled to the output of another three-phase switch, which was attached to the lines via a special, high precision, clamp-on type current transformer so that a voltage proportional to each phase current could be monitored separately.

The Harmonic Analyzer was then programmed for:

- Triggering manually;

- Taking 256 samples per measurement, and four measurements per reading;

- Measuring the total root mean square (RMS) value of the waveforms;

- measuring the RMS value of the fundamental and the percent of RMS with respect to the fundamental of the 2nd to the 50th harmonic;

- Measuring the phase angles with respect to the fundamental of the 2nd to the 50th harmonic;

- Measuring the fundamental frequency; and

- Performing complex voltage, current, and power measurements.

Table A-1. Instrumentation List

Description	Manufacturer	Model
Power Demand Analyzer	Dranetz	808
Precision Power and Harmonic Analyzer	Dranetz	3105
Desktop computer	Tektronix	4052 A
Storage Oscilloscope	Nicolet	2090

ANALYSIS

The procedure for calculating the waveform deviation factor and constructing the distorted wave utilities: (1) data obtained from the Precision Harmonic Analyzer, a Tektronix 4052A Desktop computer, and (2) the software to perform mathematical calculations and comparisons, and to provide graphic outputs of the results.

1. The distorted wave was mathematically formed by summing its fundamental wave and every harmonic wave up to the 50th harmonic. Each individual wave was mathematically formed using (in the sine wave equation) the fundamental frequency, its harmonic (wave) number, the percent RMS value of its magnitude, and its phase angle with respect to the fundamental.

2. The equivalent sine wave was mathematically formed using total RMS value of the distorted waveform and the fundamental frequency.

3. The deviation factor of a wave is defined as the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make the maximum difference as small as possible. Knowing the equation which describes the equivalent sine wave, and the set of equations which describes the distorted wave, 256 corresponding ordinates (for one complete cycle) were calculated, and the deviation factor was determined by shifting the waves until the maximum deviation factor was determined.

4. Finally, the computer drew the equivalent sine wave, the distorted wave, and the frequency spectrum of the distorted wave.

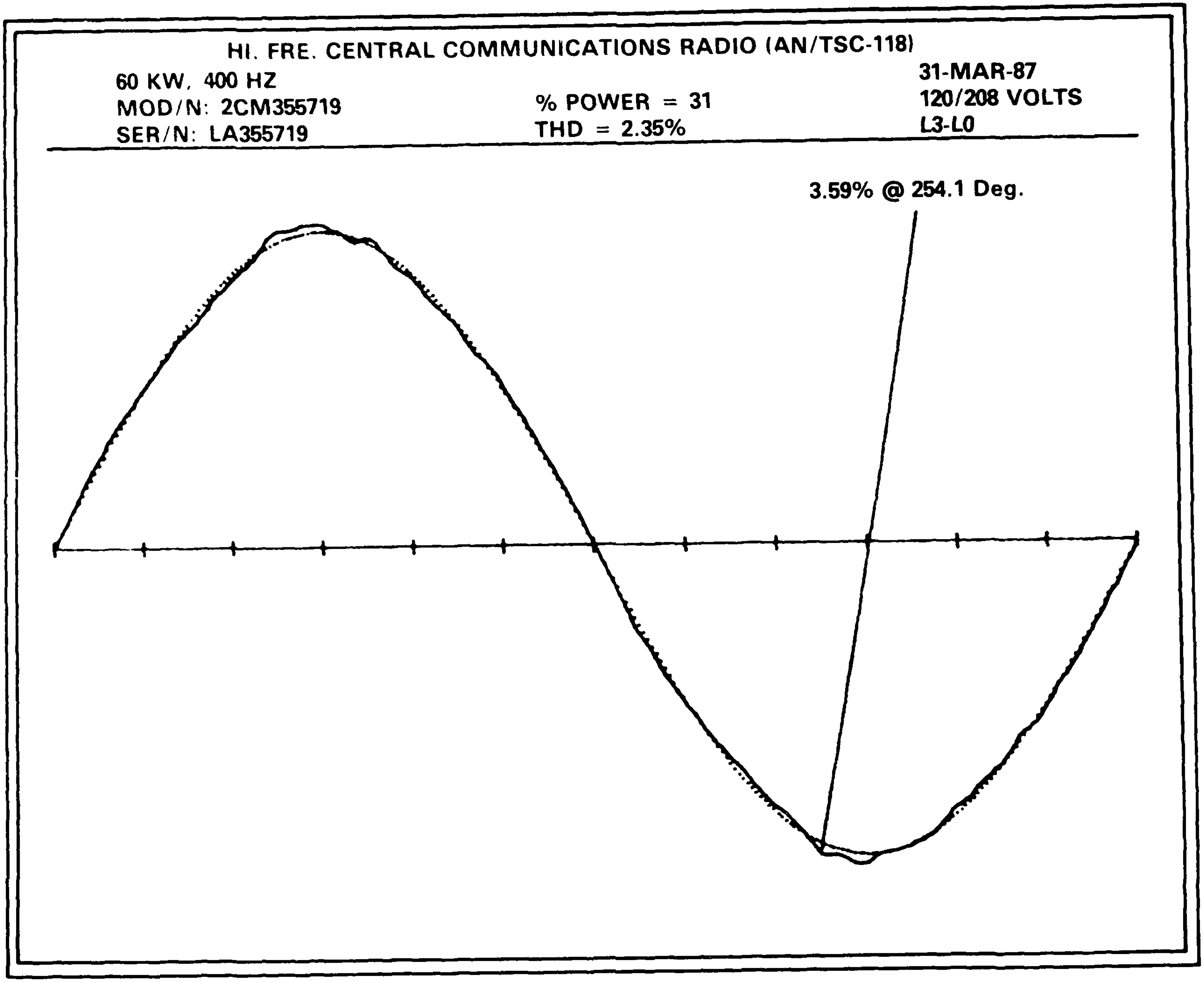
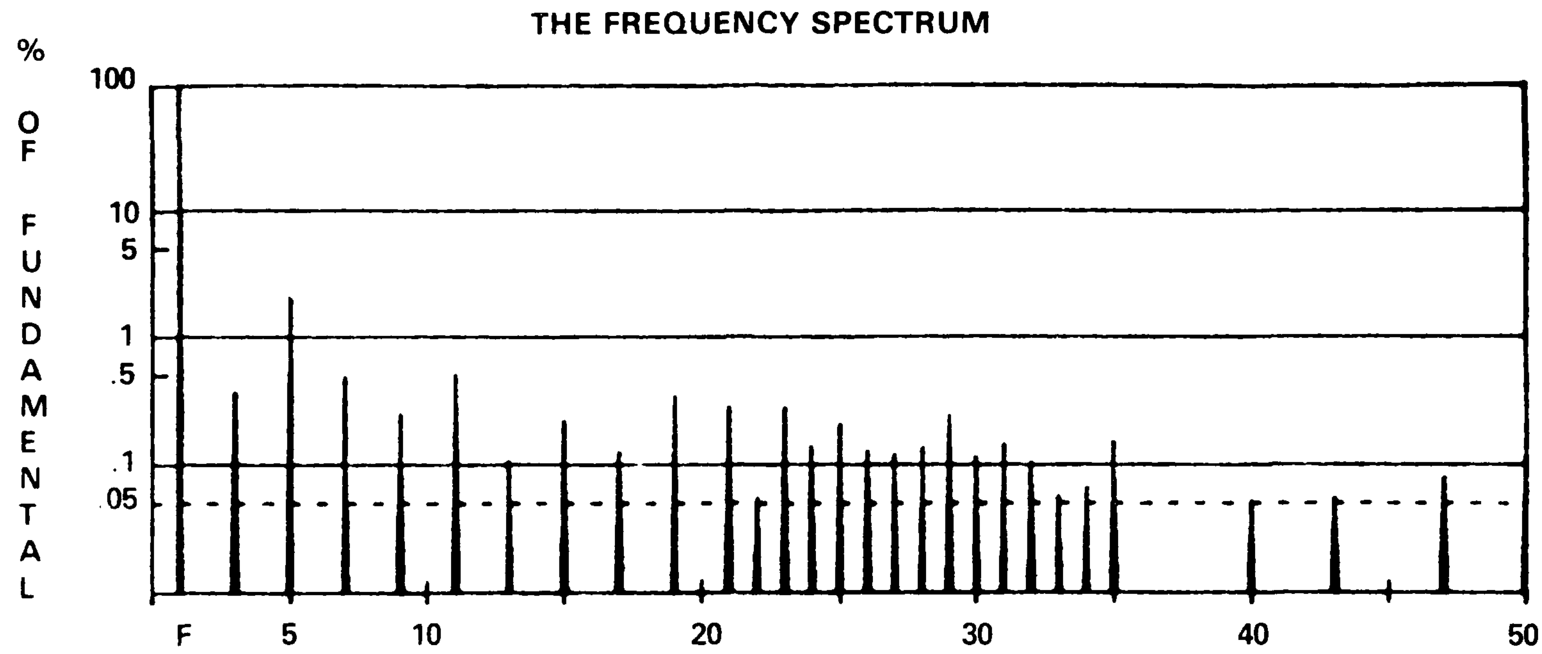


Figure A-1. Voltage Waveform Deviation



HARMONIC CONTENT > .05%

FUND 100	3 0.36	5 2.00	7 0.49	9 0.24	11 0.50	13 0.11	15 0.22	17 0.12	19 0.34	21 0.28
22 0.05	23 0.28	24 0.14	25 0.21	26 0.13	27 0.12	28 0.14	29 0.24	30 0.11	31 0.14	32 0.10
33 0.06	34 0.07	35 0.15	40 0.05	43 0.06	47 0.08	50 0.11				

THD = 2.35%

Figure A-2. Frequency Spectrum

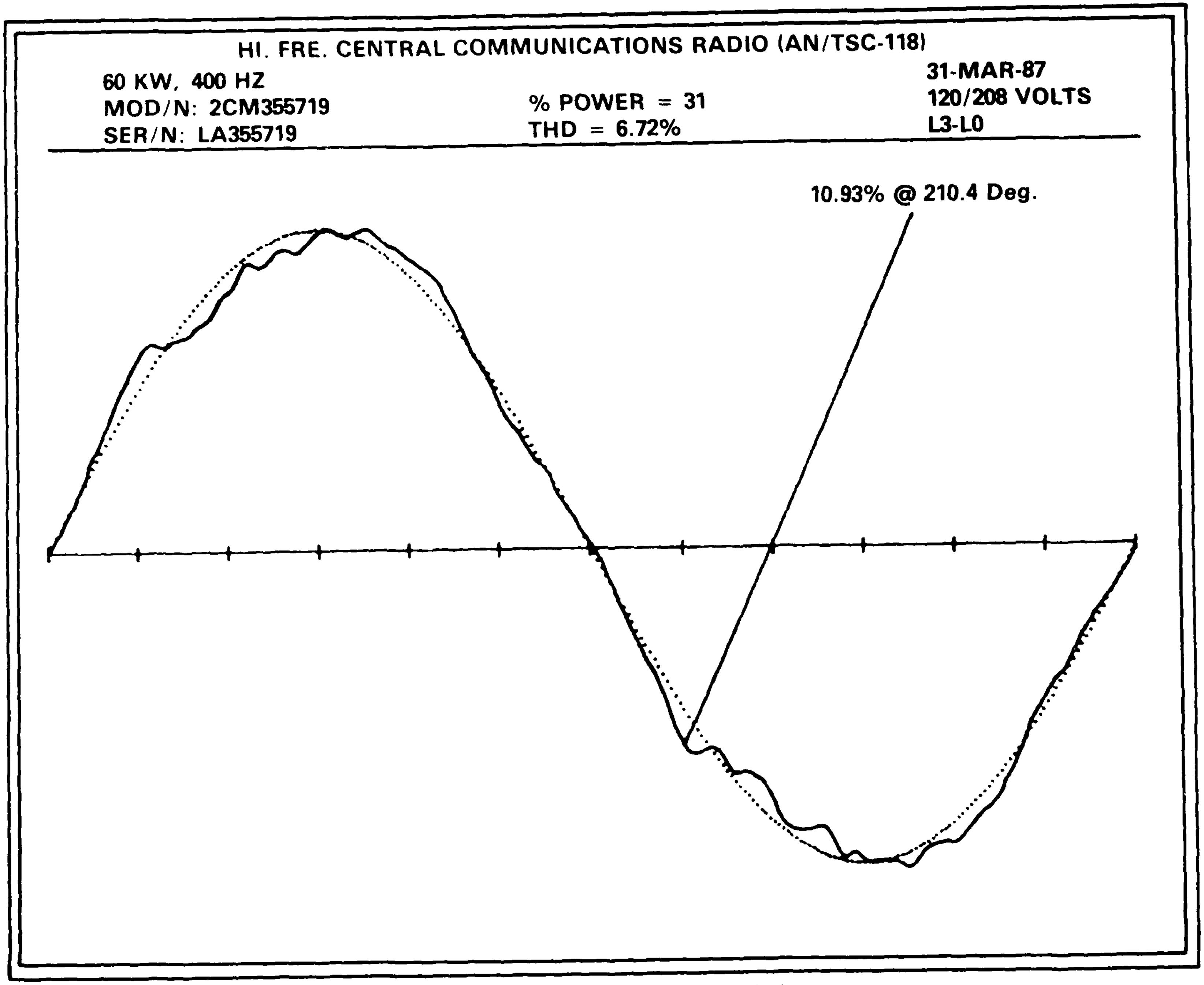
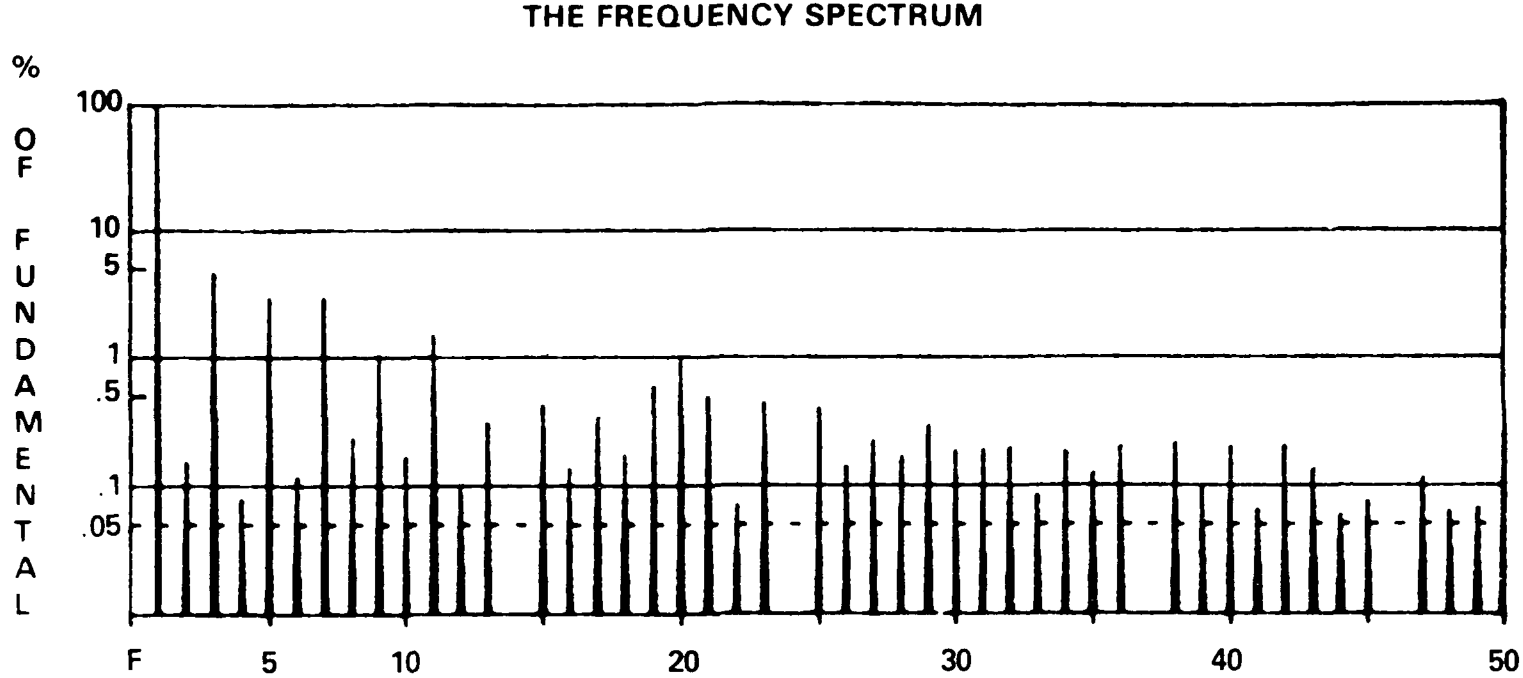


Figure A-3. Current Waveform Deviation



HARMONIC CONTENT > .05%

FUND 100	2 0.15	3 4.58	4 0.08	5 2.91	6 0.12	7 2.90	8 0.23	9 1.05	10 0.17	11 1.49
12 0.09	13 0.31	15 0.43	16 0.14	17 0.35	18 0.17	19 0.59	20 0.91	21 0.49	22 0.07	23 0.44
25 0.39	26 0.14	27 0.22	28 0.17	29 0.29	30 0.18	31 0.19	32 0.19	33 0.08	34 0.18	34 0.12
36 0.20	38 0.21	39 0.09	40 0.20	41 0.06	42 0.20	43 0.13	44 0.06	45 0.07	47 0.11	48 0.06

THD = 6.72%

Figure A-4. Frequency Spectrum

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